

July 26, 2021

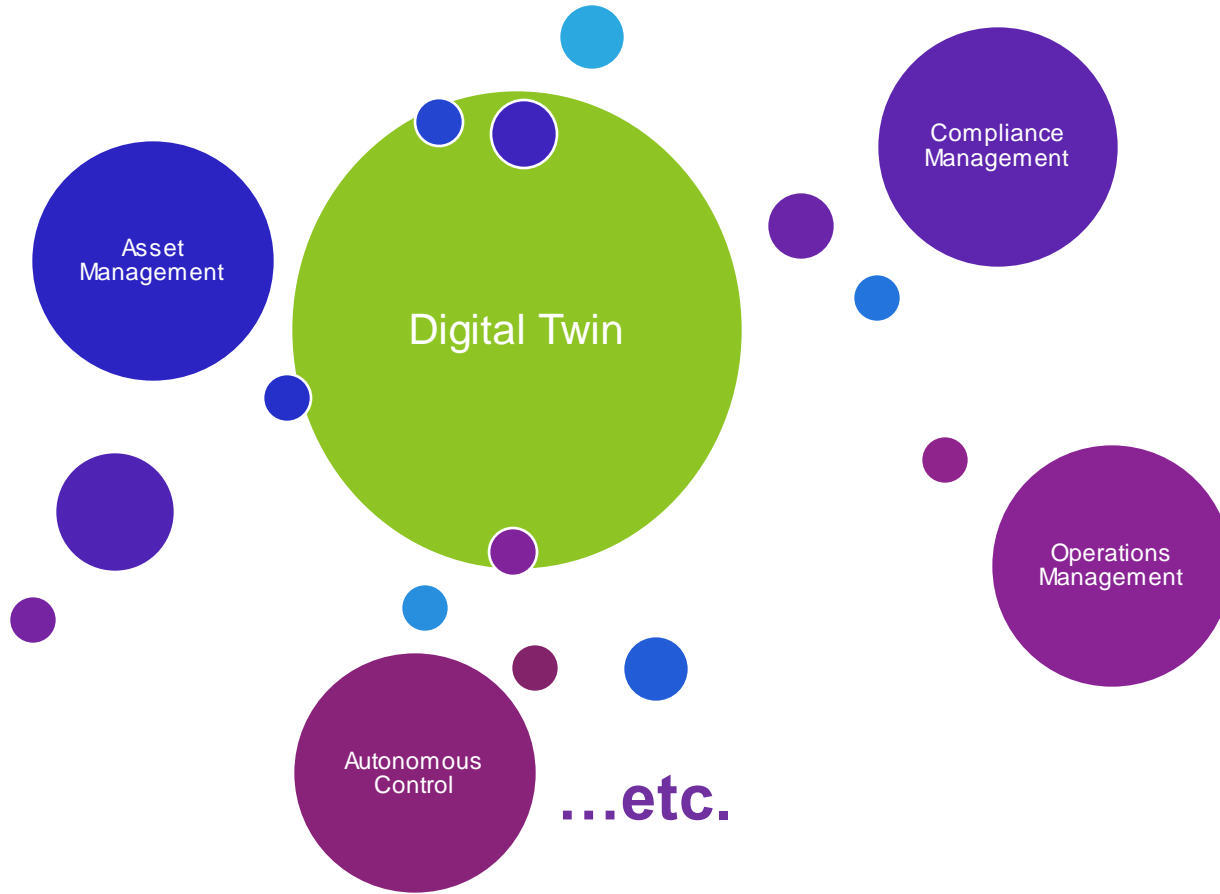
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Digital Twins in the Nuclear Fuel Cycle

July CURIE Workshop

What is a Digital Twin?



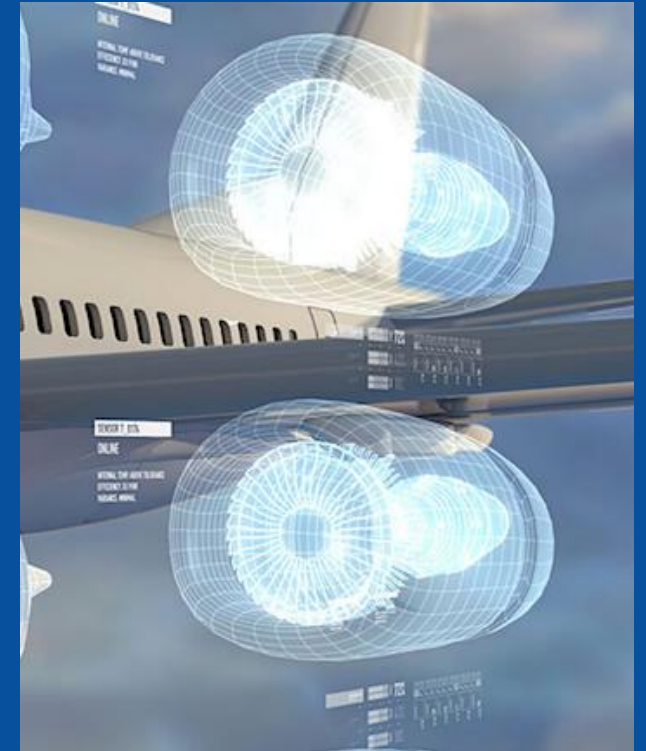
INL Definition: Digital Twins represent the merging of digital thread, controls theory, artificial intelligence, and online monitoring into a single cohesive unit, a virtual model that comprehensively captures all relevant aspects of the underlying system, utilizing bidirectional communication to track and trend both simulated and measured physical responses.

What is different than a traditional simulation?

- Integration of real-time data
- Dynamic model update (AI/ML integration)
- Real-time operator feedback (visualization)

Digital Twin Opportunity

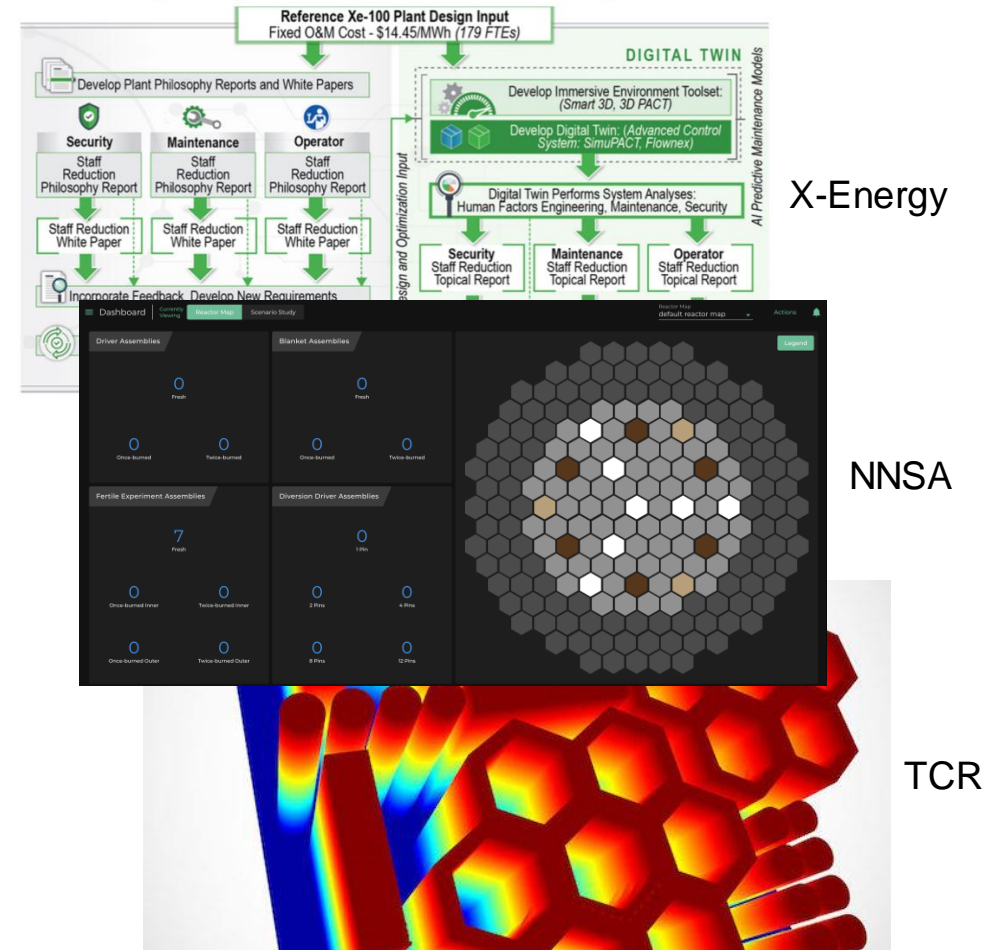
- **Operational Cost**
 - **14-23%** reduced operations cost (BCG [1])
 - **\$1.05 billion** in cost avoidance (GE [2])
- **Asset Performance**
 - **40% improvement** in first-time quality (Boeing [6])
 - **10% improvement** in effectiveness (Gartner [2])
- **Growing Market and Technology**
 - Market is **~\$3.1 billion** (2020) [5]
 - Market predicted to **\$48.2 billion** by 2026 [5]



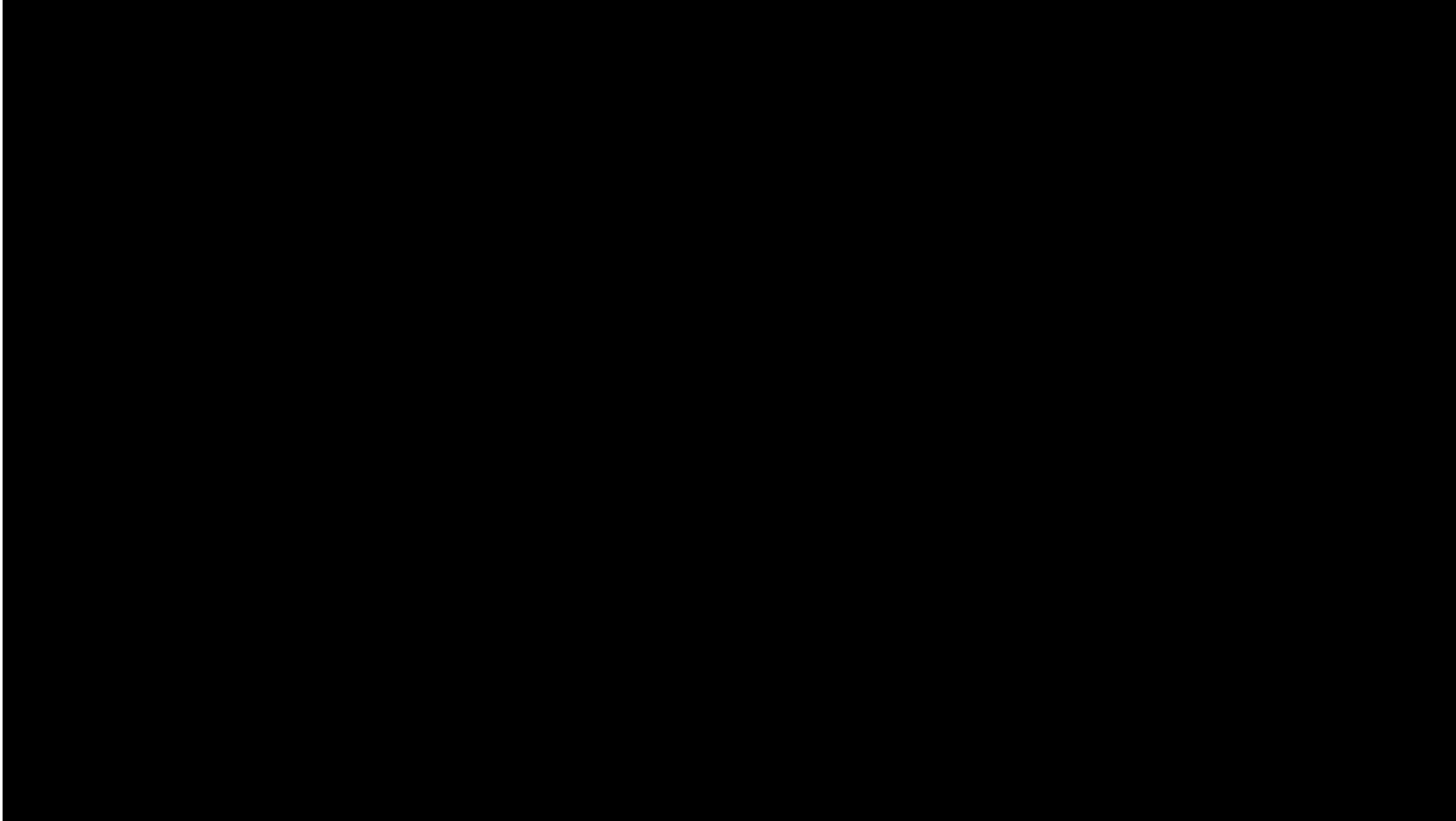
General Electric Aviation has digital replicas of every engine to monitor performance and predict maintenance issues. This approach reduces engine operational costs.

Nuclear Industry Examples

- **Generating Electricity Managed by Intelligent Nuclear Assets (GEMINA) [4]:** digital twin technology for advanced reactors to transform operations and maintenance (O&M) systems
 - ANL, EPRI, Framatome, GE Research, MIT, Moltex Energy, University of Michigan, X-Energy
- **DOE-NE**
 - **NRIC:** Model-based systems engineering (MBSE) and integrated 3D approach for test bed design
 - **TCR:** Digital platform for advanced manufacturing with integrated AI/ML
 - **VTR:** Advanced integrated digital ecosystem for reactor design with digital twin end-goal
- **NNSA:** Safeguards by Design Digital Twin



Safeguards Digital Twins Video



Digital Engineering

INL Definition: Digital Engineering embodies a deliberate transformational approach to the way systems are conceptualized, designed, constructed, operated, maintained, and retired.

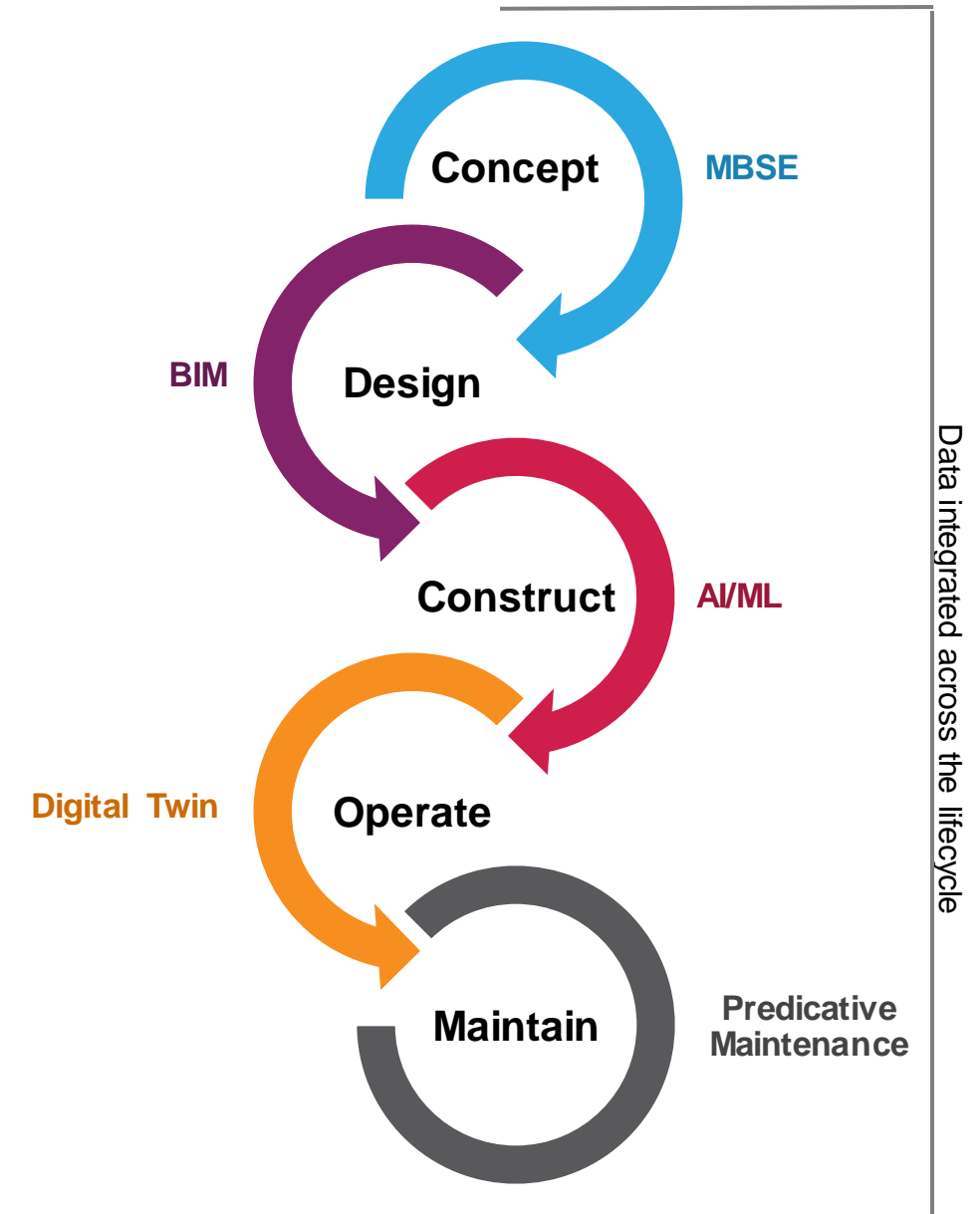
Digital Engineering Design

- **Capital and Operational Cost:** 15-25% cost savings in design, engineering, construction phase (BCG [1])
- **Schedule:** New sixth-generation stealth fighter already built with ~10-year schedule reduction [3]
- **Performance:** 25% productivity increase at Mortenson Construction using Virtual Design and Construction (VDC)
- **Risk:** Significant reduction of cascading risk (silent error) introduction in design of complex systems

AI/ML: Artificial Intelligence / Machine Learning

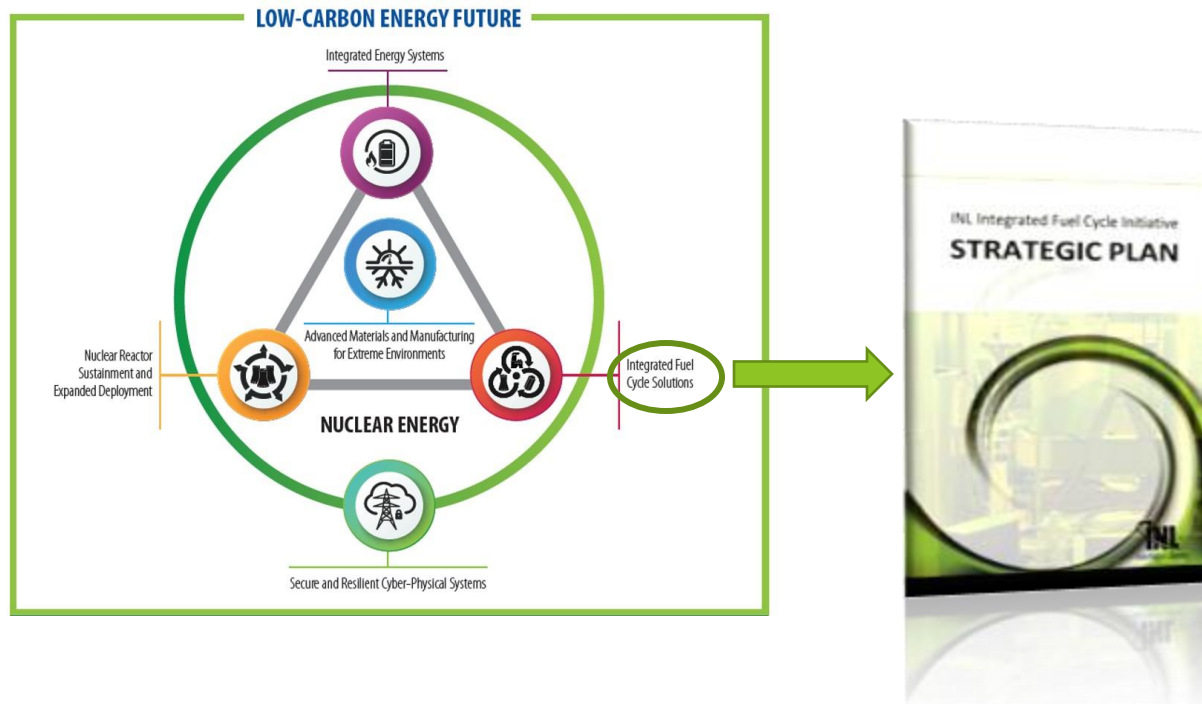
BIM: Building Information Management

MBSE: Model-Based Systems Engineering



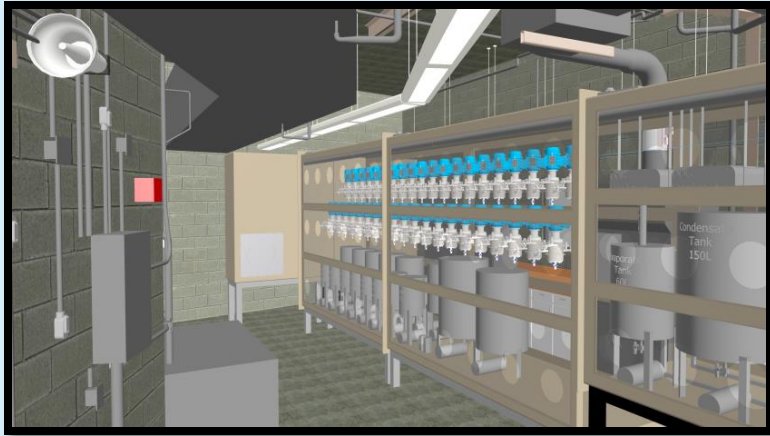
Beartooth Test Bed Vision

INL supports the safe, secure, and economic management of nuclear fuel from conception to final disposition



- Supports **sponsor diversification** by capitalizing in growing NNSA, NHS, DTRA and AI-Data Science initiatives and budgets
- Provides an integrated **civilian nuclear fuel cycle test bed capability** not available at any other national laboratory
- Develops **key infrastructure** that supports RD&D of **national security solutions** for the evolving civilian nuclear fuel cycle
- Develops **new scientists and safeguards inspectors** to support fuel cycle and nonproliferation objectives

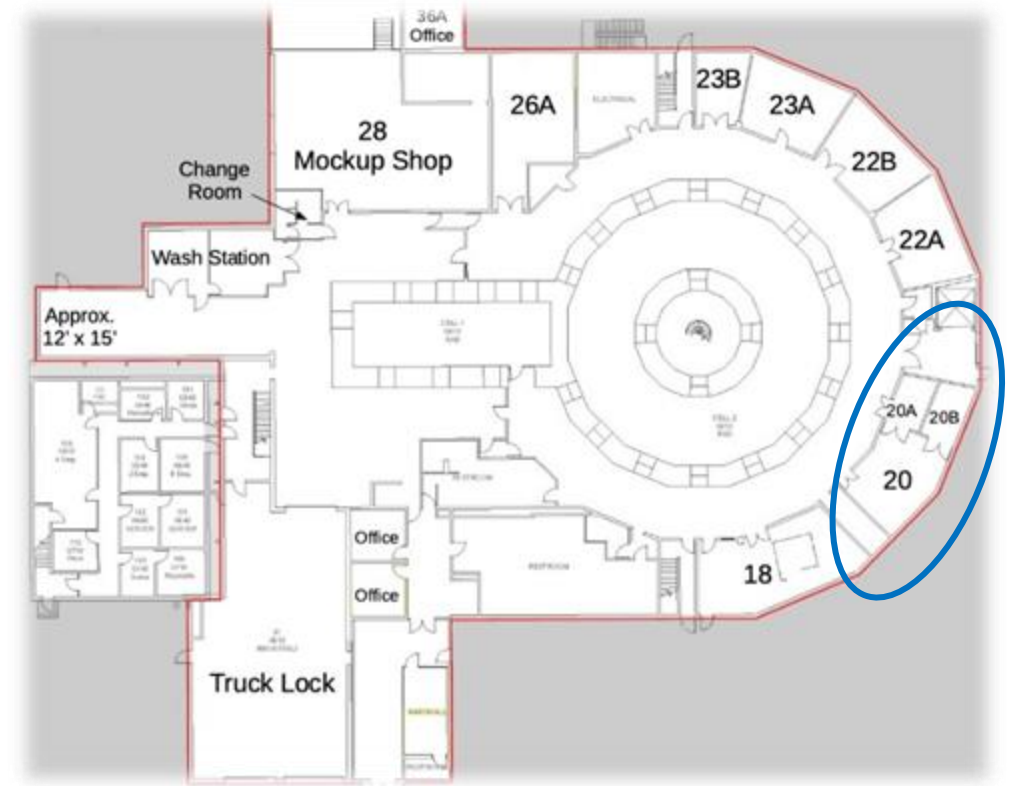
Beartooth Test Bed



Beartooth - SNM Test Bed

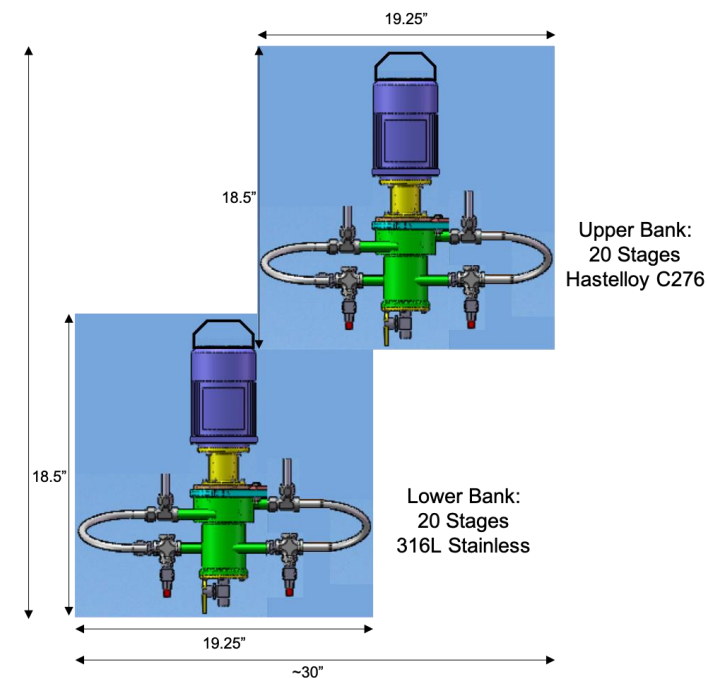
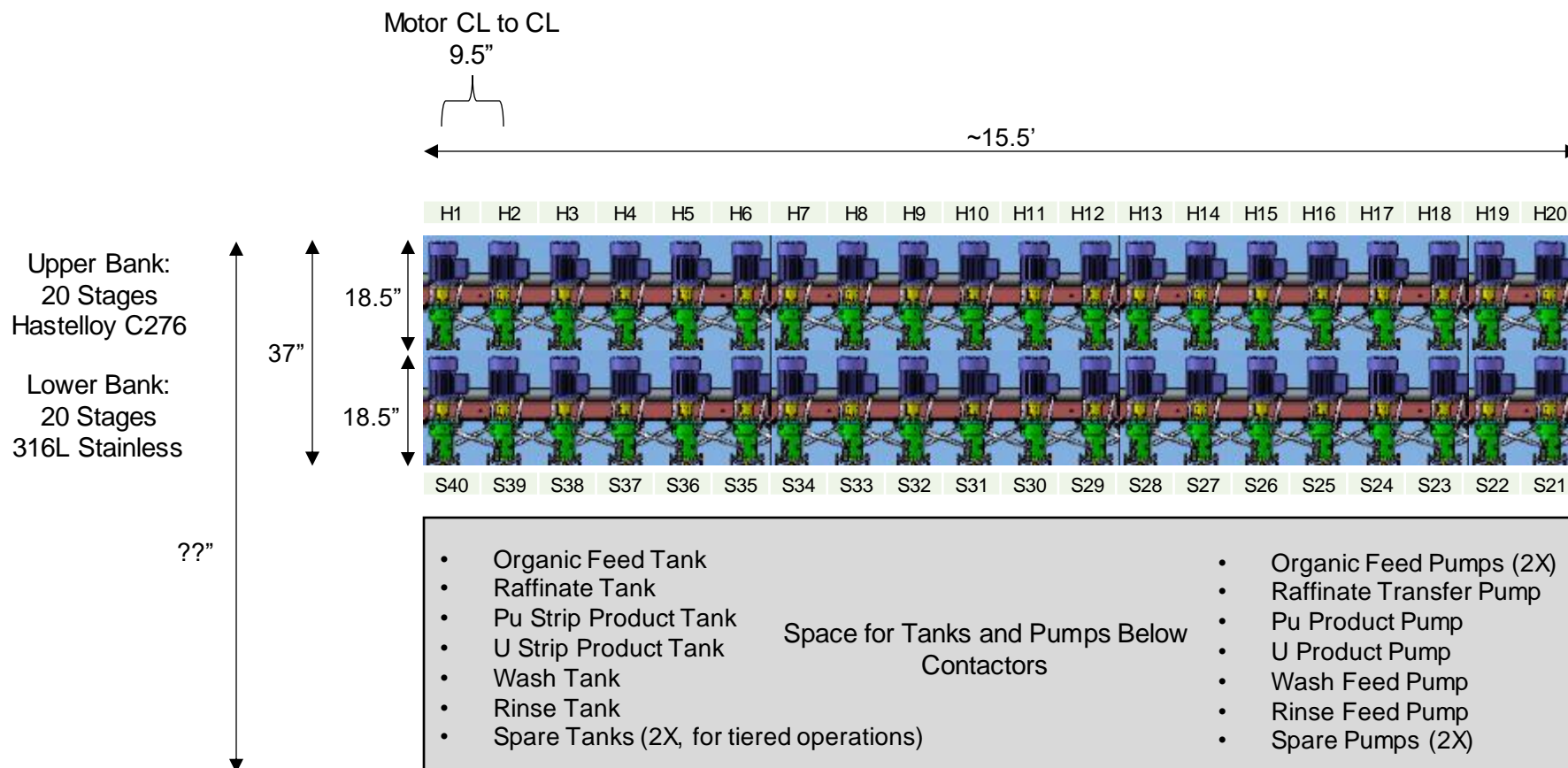
Objective – Provides an integrated civilian nuclear fuel cycle test bed capability for **testing new nonproliferation technologies**

- *Platform for instrumentation development supporting tracking and accounting of special nuclear material and proliferation detection of the evolving nuclear fuel cycle*
- *Develops new AI and ML methods to inform nonproliferation decision making*



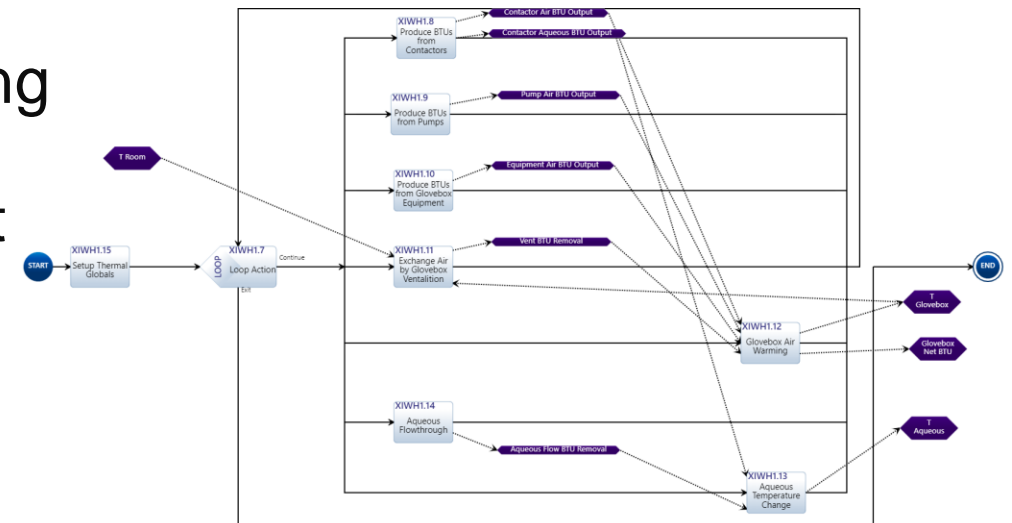
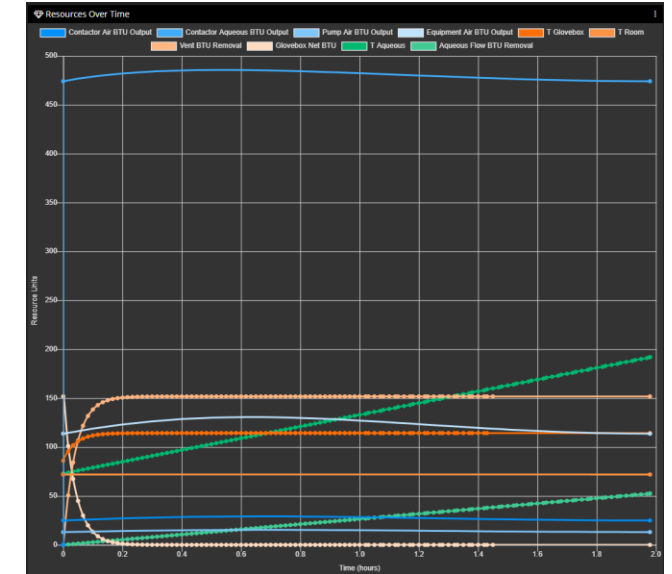
**Location – MFC FCF
Hazard Category II Facility**

Conceptual Layout: Front & Side Profile



Digital Engineering Design with MBSE

- MBSE: Integrated data approach to modeling to requirements, design, analysis, and test (V&V)
 - Enables validation of assumptions and parameters early in the process
 - Provides traceability to documentation such as requirements for traceability
 - Reduces silent error introduction: Modelling out assumptions such as heating/cooling early in the conceptual design proved that there were additional parameters or requirements that needed defined in the design.



Developing a Digital Twin for Proliferation Detection in Chemical Separations Facilities

- **Transferable Solutions**

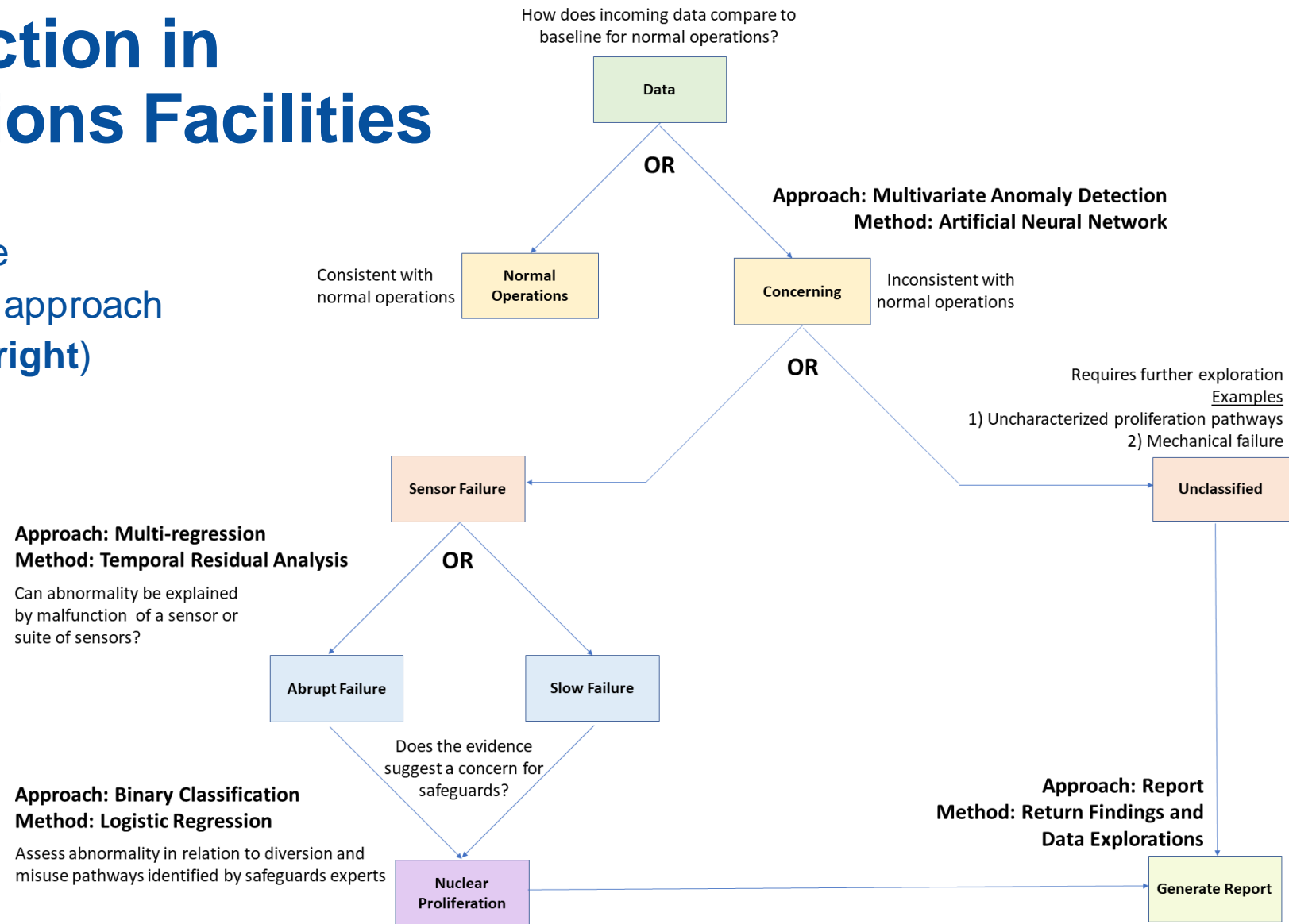
- Framework digital twin architecture
- Break AI/ML goals into simple Q/A approach
- Prescribe a data driven workflow (right)

- **Bonneville County Technology Center (BCTC) to Beartooth Testbed**

- Transparent system monitoring
- Automated status reporting
- Proliferation detection

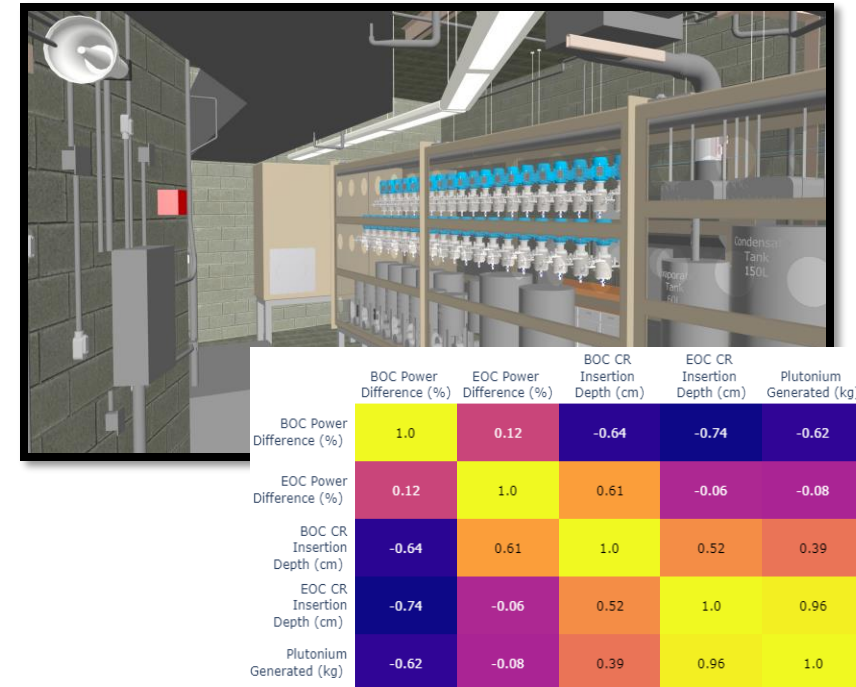
- **Flexible Approach**

- Algorithms can be specialized for individual applications
- Infrastructure remains constant



Fuel Cycle Digital Twin Summary

- Digital twin and digital engineering techniques are under application in reactor safeguards and fuel cycle facility development (**Beartooth**)
- Proven to significantly **reduce costs (14-23%)** and **increase performance** in automotive and aerospace industries
- **Transformational approach** to operation and maintenance across nuclear fuel cycle with innovation growing at a rapid pace
- Advanced nuclear digital twins **currently funded** through ARPA-E GEMINA, DOE-NE, and NNSA
- Digital engineering proven success in nuclear design: VTR has **sustained milestone performance** across a geographically dispersed team due to our digital engineering strategy
- Digital twin+ AI enables sophisticated proliferation analysis to allow mitigation of diversion and misuse scenarios through safeguards by design and real time monitoring for detection and automated conclusions
- Deployed and **advanced nuclear twins in development** in industry, academia, and the national laboratories



References

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2. <https://www.ge.com/digital/blog/industrial-digital-twins-real-products-driving-1b-loss-avoidance>
3. <https://www.foxnews.com/tech/air-force-flies-6th-gen-stealth-fighter-super-fast-with-digital-engineering>
4. Vaibhav Yadav, et al. 2021. "Proceedings of the Workshop on Digital Twin Applications for Advanced Nuclear Technologies." ML21083A132, U.S. Nuclear Regulatory Commission.
5. <https://www.computer.org/csdl/magazine/co/2021/04/09399932/1sF3E3EoCas>
6. <https://www.aviationtoday.com/2018/09/14/boeing-ceo-talks-digital-twin-era-aviation/>

Acronyms

ECl: Export Controlled Information

HPC: High Performance Computing

MAGNET: Microreactor AGile Non-nuclear Experimental Testbed

NNSA: National Nuclear Security Administration

NRIC: National Reactor Innovation Center

OUO: Official Use Only

STIC: Strategic Thermal Irradiation Capability